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Before the

Subcommittees on Energy and Research

Science Committee

U.S. House of Representatives

July 20, 2005

Chairmen Biggert and Inglis, and Members of the Energy and Research Subcommittees, thank you for the opportunity to testify today and share my thoughts on the hydrogen economy. I will address the role of basic research in bringing the hydrogen economy to fruition. As background for my testimony, I would like to introduce into the record the report on "Basic Research Needs for the Hydrogen Economy" based on the Workshop held by the Department of Energy (DOE), Office of Basic Energy Sciences. This report documents the vision of hydrogen as the fuel of the future, and the scientific challenges that must be met to realize a vibrant and competitive hydrogen economy.

Let me start my testimony by recalling the energy challenges that motivate the transition to a hydrogen economy. Our dependence on fossil fuel requires that much of our energy come from foreign sources; securing our energy supply for the future demands that we develop domestic energy sources. Continued use of fossil fuels produces local and regional pollution that threatens the quality of our environment and the health of our citizens. Finally, fossil fuels produce greenhouse gases like carbon dioxide that threaten our climate with global warming.

Hydrogen as a fuel addresses all of these issues: it is found abundantly in compounds like water that are widely accessible without geopolitical constraints, it produces no pollutants or greenhouse gases as byproducts of its use, and it converts readily to heat through combustion and to electricity through fuel cells that couple seamlessly to our existing energy networks.

Critical Challenges: Production

The enormous appeal of hydrogen as a fuel is matched by an equally enormous set of critical scientific and engineering challenges. Unlike fossil fuels, hydrogen does not occur naturally in the environment. Instead, hydrogen must be produced from natural resources like fossil fuels, biomass or water. Currently nearly all the hydrogen we use is produced by reforming natural gas. To power cars and light trucks in the coming decades we will need 10 to 15 times the amount of hydrogen we now produce. This hydrogen cannot continue to come from natural gas, as that production route simply exchanges a dependence on foreign oil for a dependence on foreign gas, and it does not reduce the production of environmental pollutants or greenhouse gases. We must find carbon-neutral production routes for hydrogen. The most appealing route is splitting water renewably, because the supply of water is effectively inexhaustible and splitting it produces no greenhouse gases or pollutants. Although some routes for splitting water renewably are known, we do not know how to make them cost-effective, nor do we know how to adapt them to a diversity of renewable energy sources. Splitting water renewably is a critical basic science challenge that must be addressed if the hydrogen economy is to achieve its long-term goals of replacing fossil fuels, reducing our dependence on foreign energy sources, and eliminating the emission of pollution and greenhouse gases.

Critical Challenges: Storage

The on-board storage of hydrogen for transportation is a second critical basic science challenge. To allow a 300-mile driving range without compromising cargo and passenger space, we must store hydrogen at densities higher than that of liquid hydrogen. This may seem a daunting task, but in fact there are a host of materials where hydrogen combines with other elements at densities 50% to 100% higher than that of liquid hydrogen. Since the 1970s over two thousand hydrogen compounds have been examined for their storage capability; none has been found that meet the storage demands. The challenge is to satisfy two conflicting requirements: high storage capacity and fast release times. High hydrogen capacity requires close packing and strong chemical bonding of hydrogen, while fast release requires loose packing and weak bonding for high hydrogen mobility. This critical storage challenge cannot be met without significant basic research: we must better understand the interaction of hydrogen with materials and exploit this knowledge to design effective storage media.

Critical Challenges: Fuel Cells

The use of hydrogen in fuel cells presents a third critical scientific challenge. Fuel cells are by far the most appealing energy conversion devices we know of. They convert the chemical energy of hydrogen or other fuels directly to electricity without intermediate steps of combustion or mechanical rotation of a turbine. Their high efficiency, up to 60% or more, is a major advantage compared to traditional conversion routes like gasoline engines with about 25% efficiency. The combination of hydrogen, fuel cells, and electric motors has the potential to replace many of our much less efficient energy conversion systems that are based on combustion of fossil fuels driving heat engines for producing electricity or mechanical motion.

The critical challenges for fuel cells are cost, performance and reliability. High cost arises from expensive catalysts and membrane materials; performance is limited by the low chemical activity of catalysts and ionic conductivity of membranes; and reliability depends on effective design and integration of the component parts of the fuel cell.

Although catalysts have been known for centuries, we still do not understand why or how they work. Our approach to catalysts is largely empirical; we often find that the best catalysts are the most expensive metals like platinum. Nature, by contrast, uses inexpensive manganese to split water in green plants and abundant iron to create molecular hydrogen from protons and electrons in bacteria. These natural examples show that cheaper, more effective catalysts can be found. The challenge is to understand catalysis on the molecular level and use that understanding to design low cost, high performance catalysts targeted for fuel cells.

Membranes are another critical basic research challenge for fuel cells. Currently fuel cells for transportation depend almost exclusively on one membrane, a carbon-fluorine polymer with sulfonic side chains. While this membrane is an adequate ion conductor, it requires a carefully managed water environment and it limits the operating temperature of the fuel cell to below the boiling point of water. We need new classes of membrane materials that will outperform the one choice currently available. Our ability to design alternative membranes is limited by our poor understanding of their ion conduction mechanisms. Significant basic materials research is needed before practical new membrane materials can be found and developed.

Meeting the Challenges: Basic Research

The three challenges outlined above are critical for the success of a hydrogen economy:

- Production of hydrogen by splitting water renewably;
- Storage of hydrogen at high density with fast release times; and
- Improved catalysts and membranes for fuel cells.

For each of these challenges, incremental improvements in the present state-of-the-art will not produce a hydrogen economy that is competitive with fossil fuels. Revolutionary breakthroughs are needed, of the kind that come only from high-risk/high-payoff basic research.

The outlook for achieving such breakthroughs is promising. The recent worldwide emphasis on nanoscience and nanotechnology opens up many new directions for hydrogen materials research. All of the critical challenges outlined above depend on understanding and manipulating hydrogen at the nanoscale. Nanoscience has given us new fabrication tools, through top-down lithography and bottom-up self-assembly, that can create molecular architectures of unprecedented complexity and functionality. The explosion of bench-top scanning probes and the development of high intensity sources of electrons, neutrons and x-rays for advanced materials research at DOE’s user facilities at Argonne and other national laboratories brings new physical phenomena at ever smaller length and time scales within our reach. Numerical simulations using density functional theory and running on computer clusters of hundreds of nodes can now model the processes of water splitting, hydrogen storage and release, catalysis and ionic conduction in membranes. These scientific developments set the stage for the breakthroughs in hydrogen materials science needed for a vibrant and competitive hydrogen economy.

Significant progress in basic research for the hydrogen economy is already occurring. Basic research on catalysis for fuel cells published in 2005 revealed that a single atomic layer of platinum on certain metal substrates has more catalytic power than the best catalysts now in use; this discovery could significantly reduce the cost and enhance the performance of fuel cells. A new route for splitting water using sunlight was created with the self-assembly of porphyrin nanotubes decorated with gold and platinum nanoparticles. These tiny nanoscale composites have already demonstrated water splitting driven by solar radiation, and they minimize manufacturing cost through their ability to self-assemble. Models of hydrogen storage compounds using density functional theory now predict the density of hydrogen and strength of its binding with unparalleled accuracy. This permits an extensive theoretical survey of potential storage materials, many more than could be practicably fabricated and tested in the laboratory.

Conclusion

The vision of the hydrogen economy as a solution to foreign energy dependence, environmental pollution and greenhouse gas emission is compelling. The enormous challenges on the road to achieving this vision can be addressed with innovative high-risk/high-payoff basic research. The great contribution of basic research to society is the discovery of entirely new approaches to our pressing needs. The phenomenal advances in personal computing enabled by semiconductor materials science and their impact in every sphere of human activity illustrates the power of basic science to drive technology and enhance our daily lives. The challenges for the hydrogen economy in production, storage and use are known. Recent developments in nanoscience, in high intensity sources for scattering of electrons, neutrons and x-rays from materials at DOE's user facilities, and in numerical simulation using density functional theory open promising new directions for basic research to address the hydrogen challenges. The breakthroughs that basic research produces in hydrogen materials science will enable the realization of a mature, sustainable, and competitive hydrogen economy.

Thank you, and I will be happy to answer questions.